JOURNAL OF THE ROYAL SOCIETY OF WESTERN AUSTRALIA.
VOL. XVIII., 1931-32.

3.—THE PHYSIOGRAPHY AND GEOLOGY OF THE UPPER SWAN AREA.

by

R. W. FLETCHER, B.Sc., and R. A. HOBSON, B.Sc.

Read 14th July, 1931. Published 6th April, 1932.

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I.—INTRODUCTION.

The Upper Swan Area, situated about twenty-five miles north-north-west of Perth on the edge of the Darling peneplain, covers an area of about five square miles. It is drained by portions of the Swan and Gatta Rivers and their tributaries.

Most of the field work was done by the authors in 1929 as part of the course in Honours Geology at the University of Western Australia, but in 1926 K. Finucane and F. G. Forman devoted some time to preliminary survey work in the area, this being necessary owing to the scarcity of survey data. Between 1926 and 1929 and also during the authors' stay, various students, under the leadership of Professor E. de C. Clarke, contributed towards the mapping of the area.

One of us (R.W.F.) is entirely responsible for the igneous and metamorphic petrology.

The work was done under the supervision of Professor E. de C. Clarke, to whom we wish to express our indebtedness.

The rainfall and vegetation of the area are similar to those of the Darlington Area (Clarke & Williams, 1926, p. 163).

II.—PHYSIOGRAPHY.

General Relief.

The model (Plate II.) constructed from the form-line map, of which Plate I. is a reduction, shows that the area consists of four dissected blocks of high relief, carved out of the western edge of the Darling Peneplain (Jutson, 1914, p. 42), the eastern blocks being separated from the western blocks by the Swan River, and from each other by the Gatta which meets the Swan in the centre of the area. The western half of the area is also divided into two blocks by a wide flat alluvium-covered saddle.

Rivers and their Tributaries.

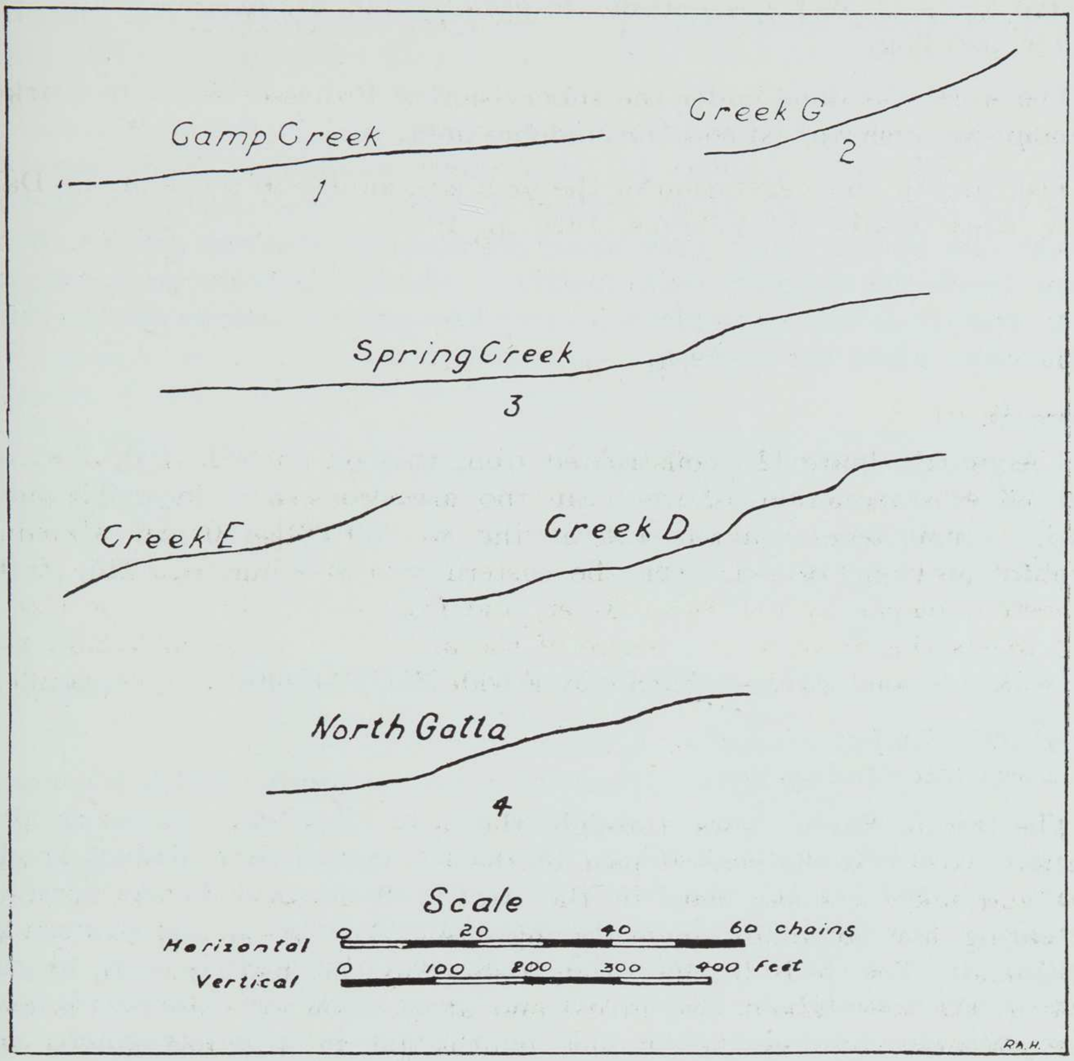
The Swan River flows through the area in a general southerly direction, except in the central part of the area where it is joined by the Gatta and takes a sharp bend to the west. The valley follows a zone of shearing and at many points along the valley a banded gneiss has been found. The bed of the Swan rises only 27 feet throughout its length in the area (about two miles) and at the lowest point is 98 feet above sea level. During the summer months the water course is occupied only by a series of pools—one of which, above the junction of the Gatta and Swan, is of considerable size. Soon after the first heavy rain the Swan begins to flow and in the winter months is a strong stream. In 1929 flow began on Saturday, 4th May, a few days after the first heavy rains.

The Swan flows out of the area through a fairly steep-sided valley, the western side of which is steeper than the eastern side. Looking at the western side from the eastern side of the valley a line of cliffs can be seen at about the 450 foot level extending parallel to the direction of the valley. If the line of these cliffs were produced, it would intersect a cliff in the valley of Creek D and also a scarp beyond the southern boundary of the area. It is suggested that this may be a line of faulting.

The South Gatta or Wooroloo Brook rises some considerable distance inland and only about 1½ miles of its course lies in the Upper Swan Area. The South Gatta flows through a fairly steep-sided valley and from where it enters the area to where it joins the Swan River there is a fall of 100 feet which is much greater than the fall in the Swan Valley. The South Gatta, just before joining the Swan, flows through a deep trench with steep sides which contrasts with the flatter nature of the stream bed higher up the valley.

At the junction of the Swan and Gatta Rivers there is a considerable amount of recent alluvium and on the west bank of the Swan a steep cliff has been formed.

Tributaries flowing into the Swan and the Gatta may be divided into four main types which are illustrated in text figure 1.



Text figure 1.—Profiles of Creeks in Upper Swan Area.

(1) Tributaries which have a flat and fairly constant grade throughout their entire length. Camp Creek is the only representative of this class. While the general profile of Camp Creek is flat there are several places where it flows over small cliffs.

(2) Tributaries which have a steep grade throughout their length. Such streams occupy narrow V-shaped valleys. To this class belong Creeks G and H and those streams flowing south into Spring Creek. Also, most of the small tributaries may be included here with the exception of two small streams flowing into the Swan, north of Creek E, which do not enter at grade.

(3) Tributaries which before entering the main stream flow over a flattened area, but which become steeper towards their source. The best example of this type is Spring Creek which originates in the N.W. portion of the area, flows in a southerly direction for just over half a mile through a steep-sided valley in which there are a number of small waterfalls, then turns S.E., meanders in alluvium for a mile, before joining the Swan. Other streams belonging to this type are Creek F and in a lesser way, Creek M and others.

(4) Streams which show one or more changes in grade throughout their lengths other than those noted in (3) above. Creeks D, E and the North Gatta belong to this type. Near to the East boundary of the area the North Gatta flows through a deep steep-sided valley.

Springs.

Springs occur at three places in the area, and in the summer months they are the only supplies of fresh water available. They are found near the camp, in the N.W. corner in Spring Creek and also in Camp Creek. In Spring Creek they occur in areas of sheared granite, but in Camp Creek the rocks are quite massive. The spring near the camp occurs in an area of alluvium and hence it cannot be seen whether or not the underlying older rocks are sheared.

Terraces.

Although flattened areas can be distinguished at 300, 400, 500, and 650 feet above sea level, they are too numerous and inconspicuous to justify correlation with those occurring at 250 and 450 feet above sea level in the valley of the Helena River. (Clarke & Williams, 1926, p. 167).

III.—GEOLOGY AND PETROLOGY.

Field Distribution of Rocks.

The country rock of the Upper Swan Area is granite, which is concealed in places by accumulations of duricrust and of alluvium. Duricrust (term suggested by Woolnough, 1927, p. 24) occurs at two very distinct levels—above the 700 foot on the flat-topped plateau remnant in the north-east portion of the area, and about the 200-350 feet levels in the western and central portions of the area. The high level duricrust is seen to grade downwards directly into granite, but at lower levels the duricrust is associated with alluvium and what may be referred to as a ferruginous sandstone. More will be said about this later. This ferruginous sandstone has also been found associated with the high level duricrust, but in much smaller quantities.

The alluvium covers a considerable portion of the area and is characterised by the occurrence of well rounded quartz pebbles. The distribution of this alluvium has been indicated on the map and model (Plates I. and II.). It is difficult, however, to mark an exact boundary, but alluvium has been indicated wherever these rounded quartz pebbles are known to occur. Further, no distinction has been made between the very recent alluvium of the Swan and Gatta Rivers and the older alluvium occurring at higher levels than those of the present rivers.

Outcropping through the alluvium in the valley of the Swan is a belt of banded gneiss with distinct augen structure. This belt is sandwiched between gneissic granite which grades on both flanks into normal granite. The granite of the western part of the area is a white variety which differs to some extent in appearance and mineral composition from the grey granite of the eastern part of the area, but in spite of these differences they are apparently parts of the same igneous mass. The succession of acid rocks in an east-west section is therefore as follows:—Grey granite, gneissic granite, banded gneiss, gneissic granite, white granite.

The basic rocks of the area consist of epidiorite dykes which invade the granite and gneiss. Many of these dykes have a rough north-south trend, but this is not universal. They are all small dyke bodies, rarely more than a chain or two in width, and some may be followed along their strikes for a mile or more whilst others can only be traced for a few chains. In the south-east quadrant of the area epidiorite dykes are particularly numerous and most of them are persistent over long distances, whereas in the north-east quadrant they are rare, those that do outcrop being very narrow and usually non-persistent. Most of the dykes are massive, but in the gneissic parts of the area, some are sheared.

Granite.

The composition of the granite, indicated by numerous micrometric analyses, is as follows :—Quartz, 20–40 per cent. ; felspar, 40–70 per cent. ; biotite, 4–10 per cent. ; muscovite, nil–4 per cent ; epidote, nil–4 per cent. The altered state of much of the felspar renders impossible an accurate estimate of the quantity of each variety present.

The main differences between the white granite of the western portion, and the grey granite of the eastern portion of the area are set forth in the following table :—

	Group I.—White Granite—Western.	Group II.—Grey Granite—Eastern.
Macroscopic ...	Felspar, quartz, and muscovite form a white background for evenly distributed green-black biotite.	Felspar and quartz are not contrasted in colour against the green mica owing to the greyish and greenish tinges of the weathered felspar.
Microscopic ...	Appreciable quantities of primary muscovite, epidote, and biotite (Percentages are : biotite, 5–10 per cent. ; muscovite tr.-4 per cent. ; epidote, tr.-4 per cent.).	Small quantities of primary muscovite, epidote, and biotite (Percentages are : biotite 4–5 per cent. ; muscovite, nil-trace ; epidote, nil-trace).
	Ilmenite and leucoxene absent	Ilmenite and leucoxene present.
	Weathering less pronounced than in Group II.	Weathering more pronounced than in Group I.

Group I.—White Granite.

Type Specimen—6613.*

This specimen, which is characteristic of the group, is a holo-crystalline medium-grained rock containing quartz, felspar, biotite and muscovite. The quartz is generally water-clear while the felspar is white to cream in colour and slightly kaolinised in places. Green to black biotite occurs as small books or flakes evenly distributed throughout the rock. Silvery muscovite flakes are less abundant. The average sizes of the components are quartz, 2 mm. ; felspar, 3 to 4 mm. ; biotite, 2 mm. ; and muscovite, 1–2 mm. in diameter.

The texture observed under the microscope is granitic, the mineral outlines being allotriomorphic. The felspars are represented by orthoclase and oligoclase, both of which show the same degree of alteration, and fresh interstitial microcline and injection micropegmatite. Quartz commonly

* Specimen numbers refer to the collection of the Department of Geology, University of W.A.

occurs as large allotriomorphs, which contain numerous inclusions of biotite, epidote, apatite, plagioclase and microcline, in addition to the usual gas and liquid inclusions. Some quartz individuals are traversed by irregular cracks, whilst most of them exhibit wavy extinction under crossed nicols, thus indicating a strained condition. Biotite, which is a strongly pleochroic brown variety, contains innumerable inclusions of epidote, apatite and sphene, and occasional inclusions of zircon. Muscovite is frequently intergrown with the biotite, but is less abundant. It contains just as many inclusions and some of these are very large, while some have intense pleochroic haloes. Both micas are deformed by pressure. Usually the deformation is characterised by simple monoclinal folds, but very contorted lamellae are sometimes seen. Epidote is a common primary mineral occurring frequently as definite crystals usually associated with muscovite and biotite. It is generally pale green to colourless and is feebly or non-pleochroic. Apatite, sphene, magnetite and zircon are the accessories and they are often found as inclusions in biotite and muscovite. Sphene also occurs as independent grains.

Grovp II.—Grey Granite.

Type Specimen—8093.

The texture of the grey granite is somewhat similar to that of the white granite, but the minerals are less clearly defined owing to weathering. The felspar is white, grey or faintly green tinged, and has a waxy or a pearly lustre depending probably upon the variety. The quartz is glassy or dull and does not stand out clearly against the felspar. Biotite is distributed throughout the rock as fine scaly aggregates. This form of the biotite, combined with the alteration of the felspar, is responsible for the grey colour of the rock.

In the thin section the identity of the plagioclase is almost concealed by its intense alteration to cloudy aggregates of granular epidote and zoisite. The potash varieties, on the other hand, are extremely fresh, but as they contain numerous shreds of quartz, they should strictly be called injection micropegmatites. Apart from this micropegmatitic intergrowth, orthoclase and microcline are rare. The micas are represented by biotite and a small amount of muscovite. Most of the former is altered to green chlorite, but a few unaltered patches remain. Several biotite flakes contain sagenite webbings in which the needles (probably rutile) are arranged in three directions at 120° to each other. The most characteristic inclusions in biotite are minute zircon crystals with pleochroic haloes, and an occasional large crystal of apatite. Of the epidote present, some is undoubtedly primary, but most of it is granular and is of secondary origin. Accessory minerals are poorly represented by ilmenite (with leucoxene) and zircon, whilst apatite is rare, and primary sphene absent.

The grey granite invariably shows some degree of granulation, and this feature is displayed by a variety of granite which shares the characteristics of the white and the grey granite. In thin section the type rock (8125) of this intermediate variety exhibits intense alteration and slight granulation. Quartz occurs as large allotriomorphs with strain shadows, containing inclusions of biotite and occasionally a little epidote associated with it. The greater portion of the felspar is obscured by kaolinisation and micacisation of the orthoclase and epidotisation of the plagioclase. Contorted lamellae of biotite and muscovite are common and although both are fairly fresh, the biotite sometimes shows a peripheral alteration to finely divided chlorite scales. Zircon with pleochroic haloes, apatite and epidote are often found as inclusions in biotite, and these accessories, together with sphene, are abundant in muscovite.

A mineral which appears to be allanite is common in the type rock (8125), but it has not been observed in any other rocks of the granite groups, The mineral is light brown in colour, non-pleochroic and nearly isotropic, and it is always found enclosed by epidote. It usually occurs as rounded grains, but one individual noted was idiomorphic and crystallographically related to the epidote (Plate III., fig. 1).

Allanite exhibiting anomalous optical phenomena similar to those outlined above, has been described by several writers (Winchell, 1909, p. 186 ; Flett, 1898, p. 388 ; Mennell, 1903, pp. 345–347).

Gneiss.

Banded Gneiss.

Type Specimen 8145.—Gneissic banding is perfectly developed, and each band differs in the proportion of its minerals from the adjacent ones. The bands are of two types : large, varying from 10 to 24 mm. or more in thickness, and small, varying from mere stringers up to definite bands 5mm. in thickness. Of the large bands, some are apparently portions of slightly gneissic granite ; some are very felspathic, with little quartz and practically no biotite, and others are biotitic. The small bands consist of more or less alternating strings of biotite and felspar, the stringers of the latter varying in thickness because of lenticular swellings or eyes of felspar.

Three sections were made of the type specimen, one of the biotitic portion, another at right angles to the banding and the third of the felspathic portion.

(*a*) *Biotitic portion, containing extremely narrow bands of biotitic material.*

In section it is seen that there is not as much biotite present as indicated by the hand specimen. Quartz is the principal mineral present and it forms a heavily granulated "ground mass" for the surviving strained orthoclase plates and biotite stringers. Fresh microcline occurs as large ragged crystals with peripheral granulation. It exhibits the usual cross-hatching under crossed nicols, and in the same crystal may pass into normal untwinned orthoclase. Inclusions of plagioclase, quartz and biotite are common. Orthoclase is slightly turbid, but shows excellent cleavages. One large fragment contains inclusions of quartz and microcline, the latter forming an intergrowth, and also small plagioclase and apatite crystals. Micropegmatite and plagioclase are sparingly present. All the felspars exhibit strain shadows. The biotite is very stringy and is often altered to ragged aggregates of finely divided chlorite. Inclusions of apatite, zircon and sphene can sometimes be seen, and minute laths of muscovite when found are always associated with the biotite.

(*b*) *Section cut at right angles to the banding.*

The forms of the potash felspars and their intergrowths present in this section are :—

(i.) Microcline.
(ii.) Orthoclase.
(iii.) Orthoclase inverting to microcline.
(iv.) Perthite (orthoclase and microcline).
(v.) Injection micropegmatite.
(vi.) Graphic micropegmatite.

Most of these forms are too well known to warrant description, but several of them, as far as we know, have not yet been described in Western Australian rocks. Alling (1923) states that "the inversion of orthoclase to microcline . . . . involves a change in volume, and this introduces stress into the system" (p. 357). The straining of the orthoclase in this inversion to microcline is characterised by phantom twinning, but from Alling's microphotographs (plate I., p. 292) it seems obvious that the twinning referred to is a strain effect similar to that shown in the accompanying microphotograph of an orthoclase individual in the type rock (Plate III., fig. 2).

Injection microperthite (or micropegmatite) has been described by Colony (1923). "Frequently the end-phase products, quartz and albite, penetrate the earlier felspars, converting earlier orthoclase into a sort of 'injection perthite.'" This form has been noticed in the grey granite, but never in abundance. In the banded gneiss it is quite common. The quartz stringers or lenticles are arranged en échelon and the angle between their direction and the cleavage is always 107° or 108° (Plate III., fig. 3).

True micropegmatite of the graphic type is very common and resembles the diagrams of Iddings (1911, p. 239) and Luquer (1925, p. 99).

The biotite occurs as stringers frequently shattered into innumerable scales, some of which are partly chloritic. Sphene and apatite are abundant as inclusions, but epidote and zircon are rare. As in the previous section (8145a) the quartz is heavily granulated and muscovite is rare. About five irregular veins of calcite traverse the rock.

(c) *Felspathic Portion.*

No biotite is present in this section and with the exception of a few large grains of epidote and occasional patches of plagioclase, the rock is composed of potash felspars (and their intergrowths) and quartz. All the quartz is heavily granulated and all the felspars have wavy extinction. Some of the felspars have also undergone granulation, appearing as a delicate network with the spaces filled with granulated quartz. From the extinction measured from cleavage traces shown by occasional patches, the granulated felspar is orthoclase.

It is doubtful whether the epidote is primary or secondary. One patch in skeleton form is enclosed by allotriomorphic, apparently recrystallised, quartz.

Granite Gneiss.

Type Specimen—8106.

The texture noted in the hand-specimen is slightly gneissic, and is more evident on weathered surfaces than on the freshly broken surfaces. A pseudo-porphyritic texture is due to large pearly eyes of felspar in a dark grey biotitic "groundmass."

In section, the felspar intergrowths which characterise the banded gneiss, are seen to be very subordinate in the gneissic granite, but the delicate network or granulated "ground-mass" noted in 8145c is very common. Biotite and epidote are present in about equal quantities. The former varies in colour from brown to green, depending on the degree of alteration, and occurs as stringers or ragged patches associated with secondary muscovite, epidote and chlorite. A few fairly large flakes contain inclusions of apatite, sphene, zircon and epidote. Some of the epidote is primary, but most of it is secondary. A little primary muscovite is sometimes found in optical continuity with biotite. Plagioclase, though common, is usually very altered.

Relationship of the Gneiss to the Granite.

The main variables upon which the distinction of the types of granite and gneiss depends, are :—

(i.) The amounts of muscovite, biotite and epidote.
(ii.) The amount of micropegmatite (and other intergrowths).
(iii.) The degrees of granulation and gneissosity.

(i.) Muscovite, biotite and epidote are abundant constituents of the white granite and the intermediate variety. Wherever found these minerals occur in fairly definite proportions, so forming a mineral group in which muscovite and epidote are present in about equal quantities whilst biotite is equal in amount to both of these minerals.

In the gneisses these minerals are not very abundant although nearly always present. The grey granite contains less biotite than the white granite, and very little muscovite and epidote. There seems, therefore, to be a *gradual* decrease in these constituents from the white granite through the gneisses to the grey granite.

(ii.) Injection micropegmatite is rare in the white granite, abundant in the gneissic granite and extremely abundant in the banded gneiss. In the grey granite it is sometimes abundant (as in the type specimen), sometimes rare, depending to some extent on the degree of granulation.

(iii.) Granulation is related to gneissosity. The banded gneiss is more heavily granulated than the gneissic granite and is apparently more dynamically affected than the latter.

The field and petrographic relationship of the gneiss to the granite suggests that the gneiss is a phase of the granite, belonging to the same period of intrusion.

A possible explanation of the origin of the gneiss is as follows :—

A granitic magma invaded the area and commenced to crystallise on its margins, so forming the Eastern and Western belts. At the time of intrusion a period of diastrophism was beginning, and while the diastrophism was not severe the margins were able to crystallise as normal granite. With intense diastrophism the centre portion, which had not yet solidified, was forced to crystallise as gneiss.

In both gneisses, quartz was the last mineral to crystallise, and, owing to the accompanying pressure, some of it was squeezed into the earlier formed felspars, so forming the injection micropegmatite. The banded gneiss, which was subjected to very great pressure, contains more micropegmatite than the granite gneiss, which suffered considerably less pressure.

The granulation was subsequently imposed, and is believed to be due to another diastrophism accompanying, or subsequent to, the intrusion of the epidiorite dykes, for some of these dykes, where intruding gneissic belts, are sheared. The primary gneiss was granulated by this diastrophism according to the degree of its gneissosity, the banded gneiss being more granulated than the gneissic granite.

Epidiorite.

The term epidiorite was applied by Gumbel in 1874 to "diabases affected by regional metamorphism." Teall (1885, p. 198) describes rocks of the epidiorite type occurring in the highlands of Scotland. "The hornblende may be fibrous, actinolitic or compact. It often occurs as extremely ragged plates containing detached granules of a water clear mineral having the refraction and double refraction of quartz. The forms of the original pyroxene grains are for the most part lost, so that replacement of pyroxene by hornblende cannot be strictly described as a case of either pseudomorphism or paramorphism. The modification of the pyroxene is accompanied by a modification of the felspar. In the epidiorite this mineral usually occurs as aggregates of irregular water clear grains in which needles and grains of hornblende occur as inclusions . . . . . . The outlines of the felspar areas in the epidiorite do not correspond with those of the felspar areas in the original rock."

The Upper Swan epidiorites present some variety in texture and composition. Some of them appear to be identical with Teall's epidiorites, whilst others are quite different. The hand specimens show considerable variation from fine to coarse grained epidiorite. Some are very felspathic ; others are very hornblendic ; but when examined under the microscope they are seen to vary between two extremes of texture, each of which is characterised by its own association of minerals. The members of Group I. are found in western portions of the area, and those of Group II. are confined to eastern portions.

Group I. (Western.)	Group II. (Eastern).
Texture intergranular. Hornblende laths and tablets embedded in a quartz felspar mosaic.	Texture usually obscured by alteration. Where definitely seen it is ophitic. Plates and tablets of hornblende enclosing felspar laths.
Hornblende is a strongly pleochroic blue-green variety usually containing abundant quartz inclusions. Occurs usually as laths.	Hornblende is a dirty green-brown variety, feebly pleochroic. Occurs usually as dense mats or large plates.
Felspar is usually granular and is untwinned.	Felspar when not zoisitised or obscured by alteration products is in large plates or laths, always twinned.
Magnetite and sphene present.	Ilmenite and leucoxene present.
Apatite rare.	Apatite common.
Quartz common.	Quartz not common.

Group I.

Blue green hornblende laths and tablets embedded in a quartz felspar mosaic. Quartz is common ; sphene usually present ; apatite is rare.

Type specimen—8085.

This is a very coarse, even-grained rock with a gabbroid texture, composed of an aggregate of green-black hornblende and pale pink felspar, the latter very subordinate in amount to the hornblende. Small white veins (·5mm. in thickness) traverse the rock.

Under the microscope, the hornblende appears in a variety of forms ranging from small laths or needles up to large irregular plates, all of which are embedded in an allotriomorphic aggregate of quartz and felspar. The hornblende is a strongly pleochroic variety, the pleochroism ranging from light yellow-green to dark blue-green. Its inclusions are numerous, and, together with the hornblende they produce a poikilitic texture on a small scale (Plate III., fig. 4) in parts of the section.

The most common inclusion is quartz, which appears as small shapeless grains embedded in the hornblende plates, and from the detached nature of minute grains and needles of hornblende embedded in quartz it is evident that the quartz crystallised later than the hornblende and some of it was squeezed into already formed crystals of hornblende. Magnetite and sphene are other inclusions, and they are always much larger than the quartz grains and are always closely associated with each other.

The felspathic portion of the rock consists of allotriomorphic grains of untwinned felspar and quartz enclosing grains of epidote, aggregates or strings of granular zoisite, needles, grains and small laths of hornblende. In addition to these minerals the felspar is coated with extremely minute grains or scales which cannot be identified. The epidote minerals often form minute skeletal networks with the interstices filled with quartz. A vein of zoisite traverses the rock, cutting through several large plates of hornblende.

Group II.

Ophitic texture characterises this group. Some members, however, do not show the ophitic texture very well due to the breaking up of the hornblende into innumerable grains and small laths, which are now embedded in the felspar.

Type specimen—8097.

This is a dark grey coarse-grained rock consisting of a compact aggregate of green-black hornblende crystals and dirty felspars which do not stand out well.

The microtexture is typically ophitic. Hornblende tablets adjoin or penetrate each other to form a large mat enclosing huge laths and plates of felspar.

The hornblende is a pale green feebly pleochroic uralitic variety which has been partly chloritised, for large plates which appear homogeneous in plane polarised light, present a flecked appearance under crossed nicols, the interference colours ranging from 1st to 2nd order. This is evidently due to heterogeneity in composition. Magnetite dust is often peppered through the hornblende. The felspar is a smoky brown colour, is perfectly fresh and shows remarkably good twinning. Inclusions in the felspar are abundant, and they consist mainly of pale blue hornblende needles and grains of zoisite. They are not, however, evenly distributed throughout the felspar, but are mostly confined to the boundaries of the laths which penetrate each other, or to cracks traversing the felspars. There are thus portions of the laths which are perfectly free from inclusions and which appear remarkably fresh, quite unlike the evenly distributed zoisite grains in saussuritised felspar.

Any small interstices left between felspar and hornblende plates are filled with quartz. Wherever felspar is seen in contact with hornblende, the latter has been changed to the deep blue strongly pleochroic variety characteristic of group I. This variety fringes the felspar-hornblende contact and is evidently a reaction rim. The feature of this rim is that it does not grade into the uralite but ends abruptly.

Ilmenite and leucoxene are not very abundant in this rock, but there are several skeletal patches of magnetite with biotite filling the interstices. These skeletons are always surrounded by uralite. Quartz and apatite are not abundant, but in two other rocks of this group, 8141 and 8100, apatite, ilmenite and leucoxene are all fairly common.

Relationship between the two Epidiorite Groups.

The two epidiorite groups represent the two extremes between which all epidiorites in the area vary. There must consequently be intermediate types which cannot be definitely placed in one or the other group. Most of these intermediate types, including sheared epidiorite, are found occupying a broad north-south belt in the centre, whereas the epidiorites which can definitely be grouped are found in the extreme eastern and western portions of the area.

The field distribution and petrographic characteristics of the granite and gneiss are therefore paralleled by the field distribution and petrographic characteristics of the epidiorite. Both rock groups are more acid in the western than in the eastern parts of the area and both have an intermediate zone, in which the Swan River now flows, where banded gneiss has taken the place of the granite, and sheared epidiorite that of the massive epidiorite.

Origin of the Epidiorite.

Gumbel defined the epidiorites in general, as metamorphic rocks, but in the Darling " Range " (the Upper Swan area in particular) it is difficult to see how the epidiorites can be of metamorphic origin, for both the epidiorites and the granite into which they are intruded are, as a rule, quite massive and show no metamorphic effects.

The analyses of epidiorites from the Darlington Area (Clarke & Williams, 1926, p. 173) show that they belong to the plateau-basalt type of magma and that normally they should have crystallised as dolerites. The Upper Swan epidiorites do not differ to any marked extent petrologically from those of the Darlington Area and, therefore, may be assumed to have a very similar chemical composition.

Bowen has shown that any igneous rock may be formed from one magma depending upon the stage at which crystallisation-differentiation was arrested. For example, further differentiation of a rock about to crystallise as a gabbro may result in the formation of a diorite. But the rock would have the composition of a diorite, both mineral and chemical, whereas the epidiorites have the hornblende of the diorite, but the chemical composition of a basalt or gabbro. An extension of Bowen's theory by Colony (1923) would explain the origin of epidiorite. Colony supposes reaction will take place between the minerals already formed and the extreme end-stage products (gaseous and liquid) of the magma. This reaction is accomplished by the *squeezing* of the end stage products through the earlier formed minerals, converting them into minerals which normally crystallise at some later period. Thus augite would be converted into hornblende ; the basic felspars to more acid varieties.

The pressure responsible for the squeezing effect is assumed to play a very important part in the conversion of dolerite to epidiorite.

Assuming the pressure to have been present (and judging from the gneissic belts, it undoubtedly was) it can be seen that the texture and composition of an epidiorite would depend upon the amount of end stage products present after the crystallisation of the original essential minerals. The small amount of quartz present in the less structurally altered members of Group II., and the large amount present in the completely altered members of Group I. seem to support Colony's theory.

Suggested Stages in the Magmatic History.

The granite invaded a series of old rocks which have now been entirely removed by erosion. Accompanying this intrusion was pressure in an E.–W. direction from which relief was got by the formation of a gneissic-zone. It is obvious that with the formation of a banded gneiss in the centre there would be transition zones of gneissic granite between the banded gneiss and the normal granite on both sides.

The granite belt nearer the Darling scarp contains an abundance of the flux minerals, biotite, epidote and muscovite, which are among the last minerals to crystallise in the magma, whereas the eastern granite belt shows a comparative rarity of these minerals. The inference is that the western belt is a more acid phase of the granite.

In the gneiss a banded structure was produced as a result of pressure, but as the magma was still partly fluid, the minerals arranged themselves along the direction of gneissosity without being granulated, and the later end stage products of quartz and felspar were injected by pressure into the earlier formed felspars, producing injection micropegmatites and microperthites. The gneiss so formed possessed a banded structure, but was not granulated.

At a later period, after the consolidation of the granite and gneiss, a basic magma squeezed its way along fissures which formed when the granite had cooled and contracted, and so the epidiorite dykes were formed. Those dykes found in the extreme west of the area are more structurally changed than those in the extreme east, but they are more acid than the eastern dykes in that they contain a larger amount of quartz.

The intrusion of epidiorite was followed by pressure which sheared many of the dykes, and which produced granulation in the banded and granite gneisses.

It is believed that both intrusions, granite and epidiorite, took place in the Pre-Cambrian era, but evidence for this cannot be found in the Upper Swan area. Since the epidiorite no igneous activity has occurred, but it is more than likely that movement has taken place along lines of weakness, and, if it is assumed that the Darling Peneplain has been separated from the Swan Coastal Plain by a fault, a subsidiary movement accompanying this fault may have been responsible for shearing of the epidiorite and the granulation of the gneiss, as well as influencing the present drainage of the Swan and Gatta rivers and their tributaries.

Fragmental Rocks.

In a previous section of this paper, the nature and distribution of these have been described and sufficient has been said of the alluvium. The other fragmental rocks—the duricrust and the ferruginous sandstone are more fully described in this section.

The Duricrust.—As far as one can see from hand specimens the duricrust of different levels is similar. It is quite similar to the material occurring elsewhere along the Darling Scarp. Rounded quartz pebbles, similar to those of the alluvium, occur in duricrust close to the west boundary of the area at about 300 foot level. Low level duricrust (laterite) has been described from elsewhere in W.A. (Simpson, E.S. 1912, p. 399) as having been transported from higher levels. It is difficult to imagine that the duricrust of the saddle, despite the presence of the rounded pebbles, has been transported. It occurs in huge boulders which would surely have been broken up in transport. Thus the duricrust must have been formed at some time after the formation of the quartz pebbles and was formed in situ.

The Ferruginous Sandstone.—This consists of small rounded quartz pebbles in a ferruginous matrix. It occurs always associated with the duricrust, and at one place as one goes up a slope one passes over alluvium, ferruginous sandstone and finally on to duricrust. Whether the ferruginous sandstone forms a continuous band under the duricrust cannot be decided, but it seems reasonable to suppose that the iron of both the sandstone and the duricrust was derived from the same source and at about the same time. The rounded quartz pebbles are perhaps of similar age to the larger pebbles found distributed over a great portion of the area. Ferruginous sandstone has been found associated with duricrust at Bolgart and at Collie.

Associated with duricrust and sandstone in the saddle on the west of the area is a conglomerate consisting of rounded quartz pebbles and ferruginous pebbles about ½in. in diameter in a siliceous matrix.

IV.—RELATION OF THE TOPOGRAPHY TO THE GEOLOGY.

It has already been noted that the Swan Valley follows a zone of shearing. Creek G also flows in a zone of sheared rock. Shear zones are found also in the upper portion of Spring Creek valley, and the valley of Creek D, but these streams do not flow in areas of sheared rock throughout their entire length. Most of the spurs are found to have a "backbone" of epidiorite. It should also be remembered that duricrust and alluvium are confined to areas of more or less definite heights above sea level, but it is not necessary to enlarge on this because the occurrences of duricrust and alluvium have been dealt with in Section III. of this paper.

V.—SUMMARY.

The Upper Swan Area represents portion of a well dissected peneplain, with the surviving remnants of this old land surface approximating to a height of about 800 feet above sea level. The dissection has been accomplished by the south flowing Swan River wending its way at a low gradient to the coastal plain (which is about 70 feet below the level of the Swan where it leaves the area), the Gatta or Wooroloo Brook which flowing west meets the Swan at about the centre of the area and the numerous tributaries of these two main watercourses.

At high and low levels the igneous rocks are capped by duricrust and ferruginous sandstone, whilst in one place below the 300 foot form line, a conglomerate is associated with the duricrust and ferruginous sandstone. Alluvium occupies the present beds of the Swan and Gatta Rivers and some of their tributaries. It is also found at higher levels where it is characterised by the occurrence of rounded quartz pebbles. Where they outcrop the igneous rocks are seen to consist of granite and gneiss intruded by a network of epidiorite dykes some of which are sheared in the gneissic parts of the area. The gneiss varies from slightly sheared granite, continuous with the main granite masses of the area, to a definite banded gneiss which outcrops prominently all along the valley of the Swan and also in several tributaries. It is believed that the granite and gneiss belong to one and the same period of intrusion, and that the gneissic structure is a primary feature, whilst the granulation is due to renewal of pressure in the area which occurred later than the intrusion of the epidiorite dykes. These dykes which are probably basaltic in chemical composition, should have crystallised as dolerites, but owing to the earlier formed minerals reacting with the volatile constituents of the magma mineralogical and textural changes were produced, resulting in the formation of epidiorite.

Both granite and epidiorite are more acid and less weathered in the western than the eastern portions of the area.

Since the intrusion of the epidiorite there has been no further igneous activity.

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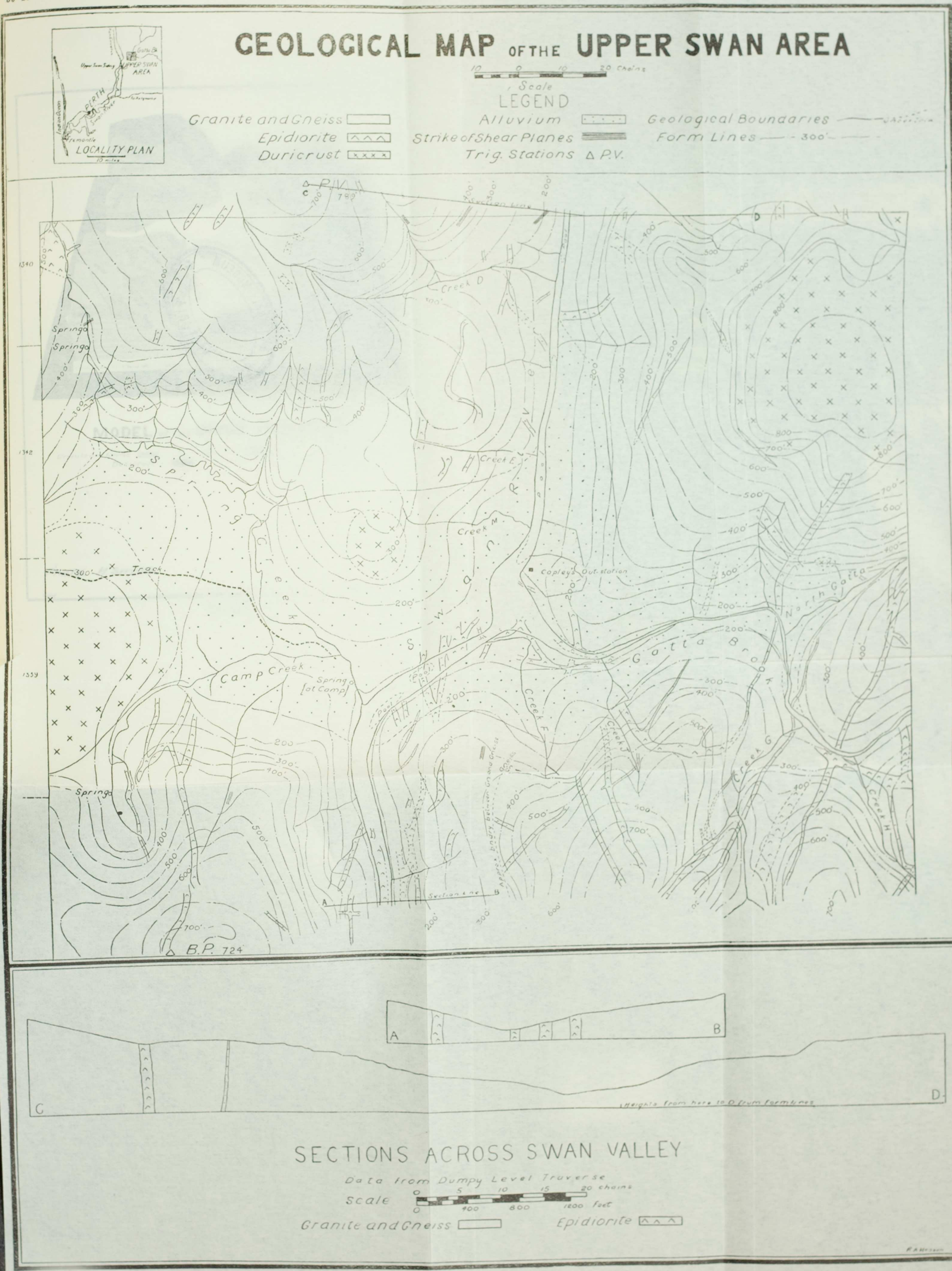
GEOLOGICAL MAP OF THE UPPER SWAN AREA
Scale
10 0 10 20 Chains
LEGEND
Granite and Gneiss
Epidiorite
Duricrust
Alluvium
Strike of Shear Planes
Trig. Stations Δ P.V.
Geological Boundaries
Form Lines 300'
LOCALITY PLAN
UPPER SWAN AREA
PERTH
Fremantle
Swan River
Indian Ocean
Spring Creek
Swan River
Camp Creek
Gatta Brook
North Gatta
Creek D
Creek E
Creek M
Creek F
Creek G
Creek H
Copley's Out-station
Track
Spring
Spring (at Camp)
Section Line
B.P. 724
P.V. 789
SECTIONS ACROSS SWAN VALLEY
Data from Dumpy Level Traverse
Scale 0 5 10 15 20 chains
0 400 800 1200 feet
Granite and Gneiss
Epidiorite
Heights from here to D from Form Lines

Plate I.

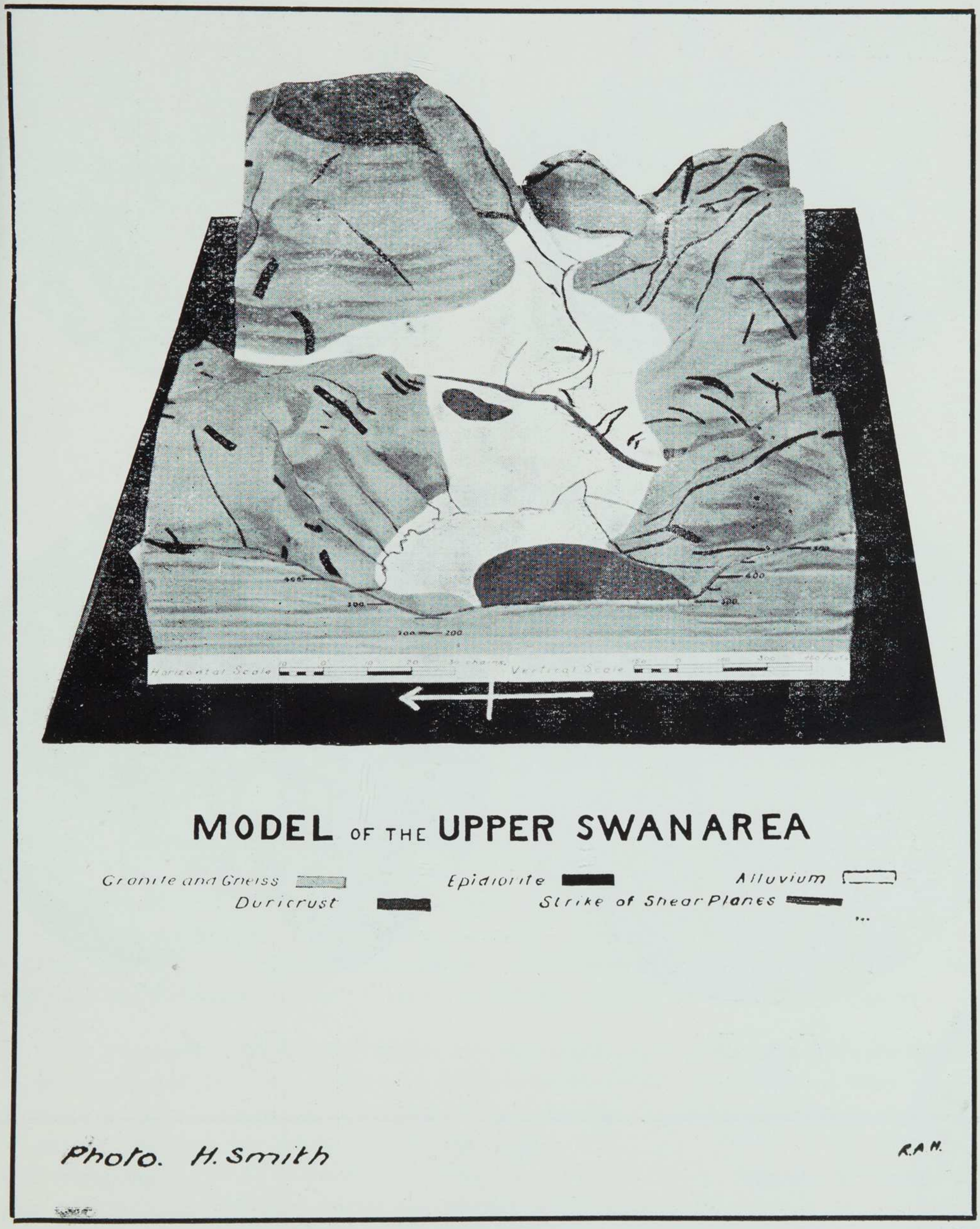
Horizontal Scale
chains.
Vertical Scale
MODEL OF THE UPPER SWAN AREA
Granite and Gneiss
Epidiorite
Alluvium
Duricrust
Strike of Shear Planes
Photo. H. Smith
R.A.H.

Plate II.

Fig. 1

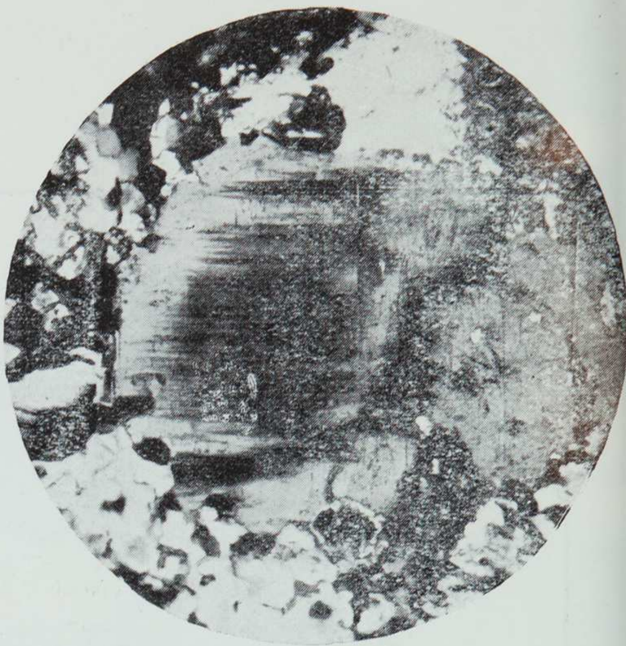

Fig. 2

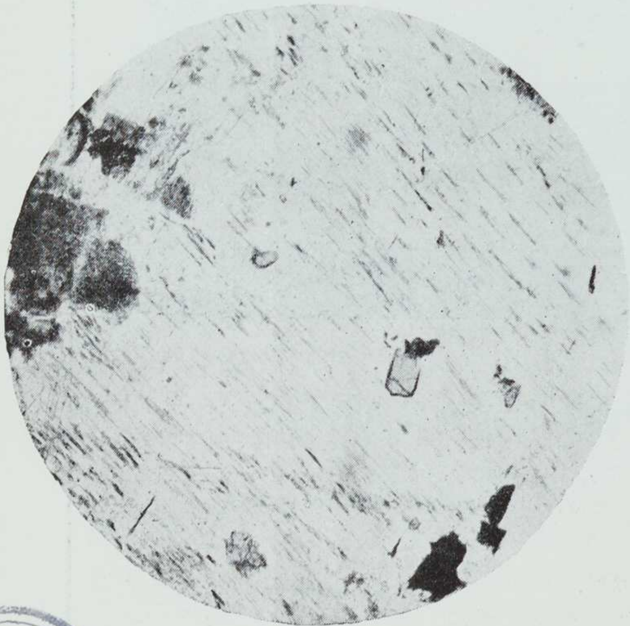

Fig. 3

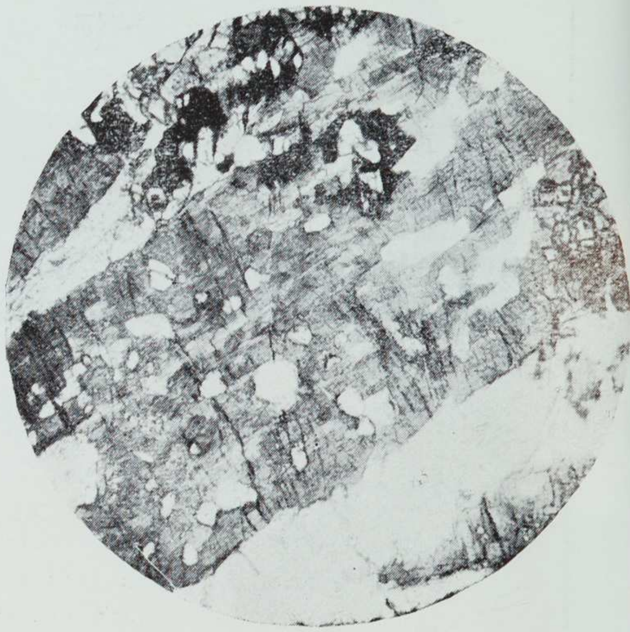

Fig. 4.

Plate III.

Photo: H. Smith. x60.

MICROPHOTOGRAPHS OF SECTIONS OF ROCKS OF UPPER SWAN AREA.

Fig. 1.—Allanite in epidote. The Allanite (A) appears colourless in the photograph, but actually it is faint yellow in colour and nearly isotropic. 8125.

Fig. 2.—Orthoclase inverting to microcline. The extreme right of the crystal is normal orthoclase. 8145b. Under crossed nicols.

Fig. 3.—Injection micropegmatite in 8145b.

Fig. 4.—Inclusions in blue-green hornblende in spec. 6572, another member of Group 1.

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